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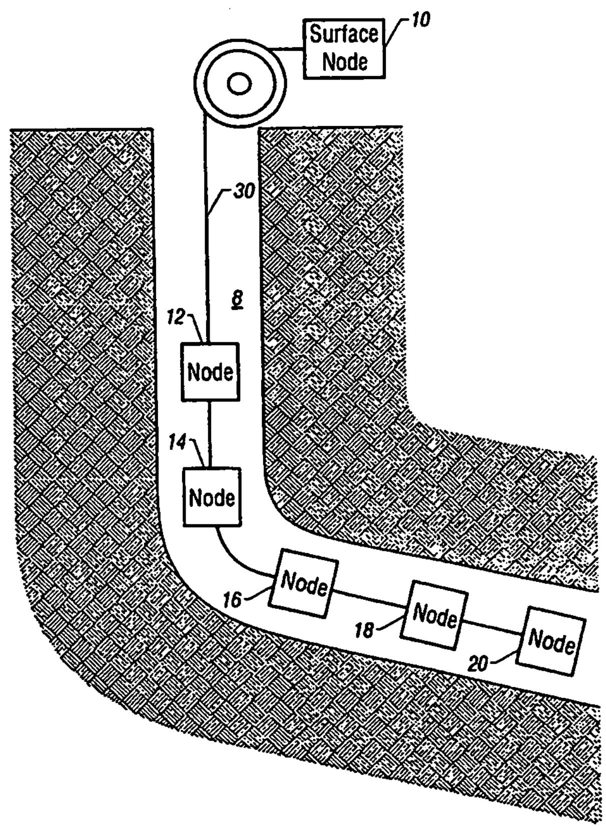
(54) Title: TRANSMITTING INFORMATION OVER A COMMUNICATION LINK

(57) Abstract

A communications system for use in a well includes a communications link and a plurality of nodes coupled to the communications link. The plurality of nodes include a transmitting node and responding nodes. The transmitting node adapted to transmit a predefined command (e.g., a special read command), and the responding nodes each includes a control device adapted to respond to the predefined command by transmitting a data block.



TRANSMITTING INFORMATION OVER A COMMUNICATION LINK

The invention relates to transmitting information over a communication link in a well.

After a wellbore has been drilled, various completion operations may be performed in the wellbore, in which equipment including packers, valves, flow tubes, and other devices may be set to control fluid production from one or more zones in the well, which may be a vertical, deviated, or multilateral well. With advances in technology, sensors and control devices may be placed downhole to monitor and to adjust downhole conditions.

An example system that monitors downhole conditions may include various downhole gauges and sensors that are capable of monitoring temperature, pressure,. and flow information. Using a communications link, such as an acoustic data link or a digital telemetry link, data gathered by the gauges and sensors may be sent to the surface to control boxes. The data may then be processed to determine the conditions downhole so that production may be improved and potential reservoir problems may be avoided. In addition to gauges and sensors, other downhole systems may include control devices that are addressable to adjust equipment settings.

To allow communications between nodes (including a surface node and one or more downhole nodes) coupled to a communications link, a communications protocol is used. One such communications protocol is the Modbus protocol, originally developed by MODICON, now a part of Schneider Automation Inc. in Andover Massachusetts. The protocol has been widely utilized, with some slight adaptations by other companies. Controllers coupled to a Modbus communications link communicate according to a master-slave protocol, in which one device (the master) initiates a transaction (e.g., a query) and another device (the slave) responds to the query by supplying the requested data to the master or by taking the action requested in the query. In a system used with a well, a master may include a controller in a surface node, and slaves may include controllers in downhole nodes.

Figs. 2A-2C illustrate data streams sent by multiple downhole nodes according to some embodiments of the invention.

Fig. 3 is a block diagram of a portion of a downhole node according to an embodiment of the invention.

Fig. 4 is a flow diagram of a sequence to retrieve information according to an embodiment.

In the following description, numerous details are set forth to provide an understanding of the present invention. However, it is to be understood by those skilled in the art that the present invention may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

According to some embodiments of the invention, a special command is defined to allow a master node coupled to a communications link to retrieve information from multiple slave nodes using the special command. The special command may include one of the following: a read command to one or more predefined addresses, a broadcast or multicast command, a write command to one or more predefined addresses, a configuration command to one or more predefined addresses, and other types of predefined commands. Once slave nodes decode the special command, each of the slave nodes may respond by providing a set of information. A general characteristic of the special command is that nodes receiving the command transmits some type of a response.

In the ensuing description, reference is made specifically to a special read command. It is to be understood, however, that other types of special commands or queries may also be utilized that require some type of response over the communications link from nodes coupled to the link. In one embodiment, communications over the communications link proceeds according to the Modbus protocol. The predefined special commands according to some embodiments may be commands defined by the Modbus protocol. However, instead of only one node responding to a special command, multiple nodes may respond to the special command according to some embodiments by successively transmitting responses to the special command. Thus, an advantage offered by such embodiments may be that an existing protocol is used for communications over a link while some or all of the

specific integrated circuits (ASICs), programmable gate arrays (PGAs), or other control devices, whether integrated or discrete. Such control devices are responsible for decoding commands transmitted on the communications link 30 and for generating responses, or optionally commands, on the communications link 30. In addition, each downhole node may be associated with a set of gauges and sensors to detect downhole conditions, including temperature, pressure, flow rates, and so forth.

The well 8 may be a vertical or deviated well (or a combination of both) with one or more completion zones, or it may be a multilateral well. During production, it may be desirable for the surface node 10 to sample the states of various downhole nodes, including for example, information indicating downhole environmental conditions (e.g., temperature, pressure, and the like), flow rate, and states of various downhole equipment, such as packers, valves, and other devices. According to some embodiments, the surface node 10 is capable of transmitting a special read command to retrieve information from each of the downhole nodes. In response to the special read command, multiple downhole nodes serially transmit the requested data over the communications link 30 to the surface node 10. By utilizing a single special read command to retrieve multiple blocks of data from multiple nodes, the communications bandwidth over the link 30 may be increased.

An example sequence of data communication from the downhole nodes to the surface node 10 in response to the special read command is illustrated in Fig. 2A. In one example configuration, the downhole nodes 12, 14, 16, 18, and 20 are configured as nodes #1-5, respectively. In response to the special read command, node #1 first transmits header information 100 up the communications link 30. The header information 100 may identify the number of blocks expected in the transmission from the nodes #1-5 in response to the special read command. After the header information 100, node #1 transmits a first data block 102. After node #1 has transmitted its data block 102, node #2 transmits its data block 104. This is followed by data blocks 106, 108, and 110 from nodes #3, #4, and #5, respectively. Finally, the last node, node #5, transmits trailer information 112 to indicate that the end of data stream has been reached. The data stream illustrated in Fig. 2A is consistent with a data stream expected by the requesting master in a query-response type communications protocol

operator desires to continuously monitor information such as downhole temperature, pressure, flow rates, and other data from the different zones in the well 8.

All or some of the downhole nodes may be configured by a setup sequence to transmit predetermined types and amounts of data. The downhole nodes may also store configuration information to determine when the downhole nodes are to begin data transmission in relation to the other downhole nodes. The setup sequence may be generated by the surface node 10 to indicate to each downhole node the type of information that is desired from that particular node. For example, the surface node 10 may request temperature and pressure information from node #1. For the other nodes, the surface node 10 may request other types of information. This is configured during the setup sequence so that the downhole nodes will respond with the requested information in response to the special read command. Other configuration information are also stored in the downhole nodes during the setup sequence. Once the setup sequence is performed, the surface node 10 does not need to generate another setup sequence until the surface node 10 wants to change the types or amounts of information or the sampling rates needed from the downhole nodes.

Referring to Fig. 3, certain components of a downhole node are illustrated. Each of the downhole nodes may be constructed the same way or with some variations or modifications. An interface block 200 couples the communications link 30 to the remaining circuitry in the downhole node. The interface block 200 may be, for example, a modem, a network interface card, or some other suitable interface circuit to manage communications with the link 30.

In the illustrated embodiment, the interface block 200 may be coupled to a bus 216 that is coupled to various elements, including a controller 202. The controller 202 is responsible for decoding commands transmitted down the communications link 30 as well as responding to these commands. Optionally, the controller 202 in some downhole nodes may be capable of generating commands or queries to transmit to other nodes coupled to the link 30. One of the commands that the controller 202 is able to decode is the special read command according to an embodiment.

Various configuration registers are located in the downhole node that are accessible by the controller 202 over the bus 216 to determine how it is to respond to

previous transmission has occurred. In one embodiment, the counter 206 is loaded with the counter reset value in the register 218 after the controller 202 detects that the counter 206 has reached zero.

To prevent a downhole node from transmitting multiple times in response to a special read command, the counter reset value stored in the register 218 may be set such that the counter 206 contains at least the value one after the last node has sent its data. Thus, in the example sequence of Fig. 2A, the counter reset value stored in node #1 will be at least one greater than the number of bytes contained in blocks 104, 106, 108, 110, and 112. While the counter 206 in node #1 still contains a non-zero value, all bytes have been transmitted up the link 30 in response to the special read command. Consequently, the controller 202 in node #1 will not transmit again.

In the example of Fig. 2C in which continuous sampling of all the downhole nodes occurs, the counter reset value 218 is repeatedly loaded into the counter 206 by the controller 202 each time the counter 206 decrements down to zero. This ensures that the controller 202 in each node re-transmits another data block after the last node has finished transmitting its data block.

In further embodiments, a field in the register 218, or alternatively, a separate configuration register, may store a value indicating the number of times the controller 202 is to transmit data blocks in response to a special read command.

In addition, a transmission wait time value may be stored in another configuration register 220 to represent the length of time in clock ticks that a node is to wait after the counter 206 has decremented to zero before beginning to transmit its data block. Thus, after the counter 206 counts to zero, indicating that the proper number of bytes have been transmitted over the communications link 30 by other nodes, the value in register 220 may be loaded into a wait counter 230. The wait counter 230 is clocked by a clock CLK. After the wait counter 230 decrements to zero, the controller 202 is allowed to begin transmitting its data. The added wait time is to allow an opportunity for the surface node 10 to issue an interrupt or another command to the downhole nodes between data block transmissions by the different nodes in response to the special read command.

The downhole node also includes another configuration register 222 to store a block packet size value. The block packet size represents the number of bytes that the

stored contiguously in physical memory in the downhole node. The storage elements 210, 212, and 214 are accessed with physical addresses. Information to be transmitted in response to the special read command may come out of non-contiguous physical address locations from one or more of the memory 210, the status registers 212, and the other storage elements 214. To allow the controller 202 to retrieve the non-contiguous blocks of data from storage elements 210, 212, and 214 based only on a single block start address in register 226, an address translation array 232 may be preloaded with address translation values. The address translation array 232 may be configured to translate the sequential addresses starting from the block start address specified in the register 226 into the non-contiguous physical addresses corresponding to the desired locations in the storage elements 210, 212 and 214.

The registers 204, 218, 220, 222, 224, and 226 are loaded by a setup sequence performed by the surface node 210 over the communications link 30. In one embodiment, write commands may be issued over the communications link 30 to write to each of the configuration registers 204-220. In addition, the address translation array 232 may also be programmed by the setup sequence to convert consecutive virtual addresses starting from the block start address into non-contiguous physical addresses to access locations in the storage elements 210, 212, and 214.

Depending on the features desired of the responding node, some of the components shown in Fig. 3 may be omitted from a downhole node. For example, a downhole node may be configured to recognize the special read command (or other special command) but is configured to respond with only one data block (i.e., these nodes do not include the multiple sampling feature). Further. some of the features described may be omitted or not used to allow communications over the link 30 to be compatible or consistent with existing communications protocols. In other embodiments, all of the features, and any variations or modifications of such features, may be implemented to achieve a flexible communications scheme.

A setup sequence is performed by the surface node when it first starts up and subsequently when the types of information needed from the downhole nodes or the node sampling rates need to be changed. Referring to Fig. 4, according to one embodiment, a data access sequence performed by the surface node 10 is illustrated. The surface node 10 first loads the configuration registers as well as the address

While the invention has been disclosed with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of the invention.

What is claimed is:

9. The method of claim 7, further comprising waiting predetermined time periods between successive transmissions by the devices.

10. The method of claim 9, further comprising transmitting another command in one of the predetermined time periods.

11. The method of claim 1, each downhole node monitoring for a predetermined amount of data to be transmitted over the communications link before the downhole node transmits its data block.

12. The method of claim 1, wherein the query includes a read command having a predefined address.

13. The method of claim 1, wherein the query includes a broadcast command.

14. The method of claim 1, comprising transmitting the query according to a Modbus protocol.

15. The method of claim 14, comprising responding to the query with a data stream consistent with the Modbus protocol.

16. A communications system for use in a well, comprising:

a communications link; and

a plurality of nodes coupled to the communications link, the plurality of nodes including a transmitting node and responding nodes,

the transmitting node adapted to transmit a predefined command, and

the responding nodes each including a control device adapted to respond to the predefined command by transmitting a data block, the responding nodes successively transmitting data blocks in response to each predefined command.

24. The communications system of claim 16, wherein one or more of the responding nodes are configurable to transmit their data blocks more than once in response to the predefined command.

25. The communications system of claim 16, wherein the predefined command includes a read command .

26. The communications system of claim 25, wherein each of the responding nodes responds to the read command by transmitting a predefined data block during its transmission period.

27. A control unit coupled to a communications link, comprising:

a controller adapted to receive a query and to monitor an amount of data transmitted over the communications link by other control units in response to the query; and

a storage element containing a predetermined value indicating a first amount of data,

the controller adapted to transmit data after it detects that the first amount of data has been transmitted by other control units.

28. The control unit of claim 27, wherein the controller is adapted to transmit data multiple times in response to the query.

29. The control unit of claim 27, further comprising storage elements and an address translator to convert addresses associated with the query to physical addresses specifying non-contiguous locations in the storage elements.

30. The control unit of claim 29, further comprising a register, wherein the addresses associated with the query includes a starting address stored in the register.

FIG. 2A

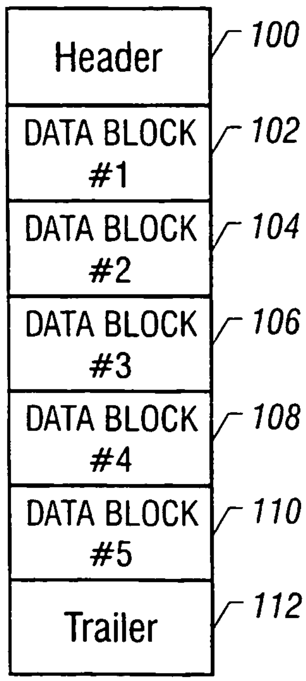


FIG. 2B

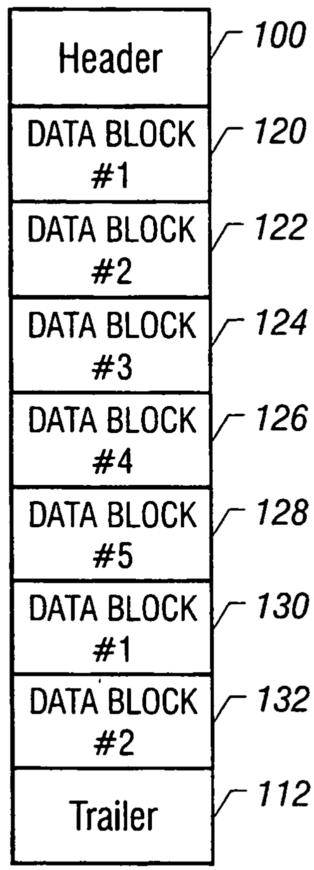
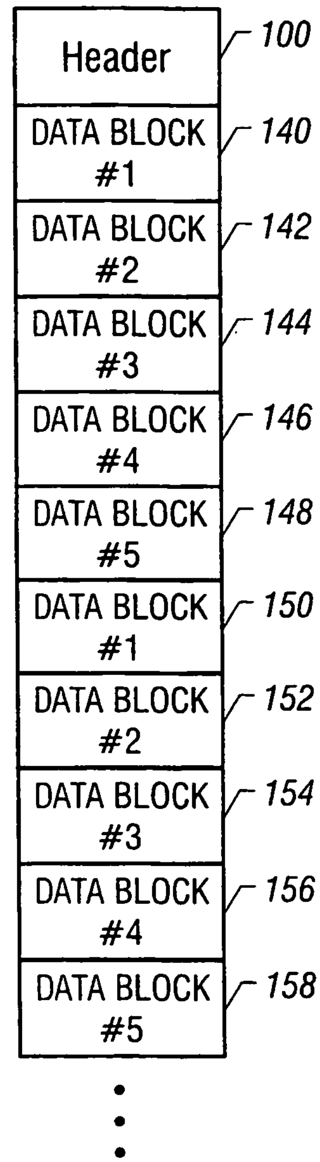


FIG. 2C



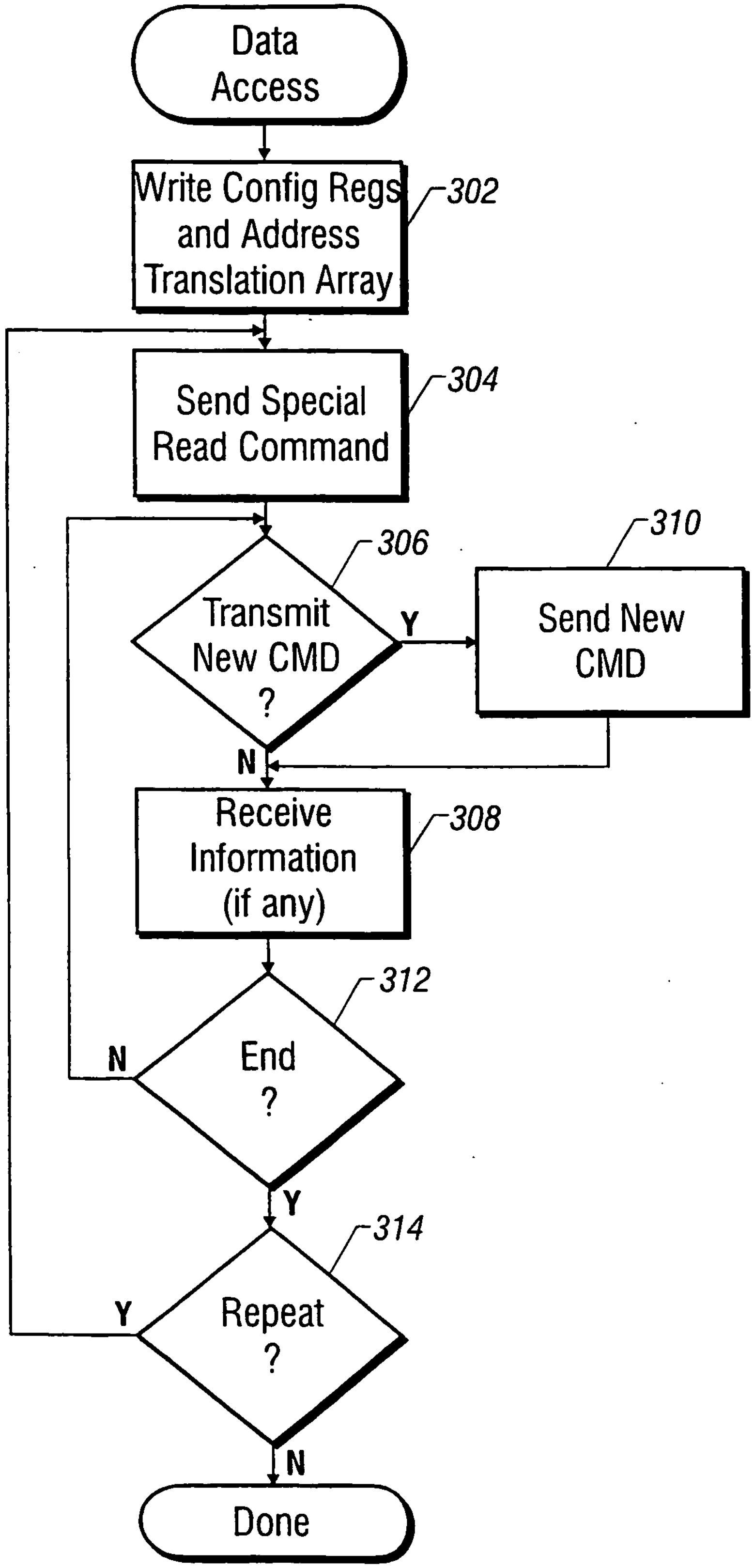

Data Access
Write Config Regs and Address Translation Array
302
Send Special Read Command
304
Transmit New CMD ?
306
Y
Send New CMD
310
N
Receive Information (if any)
308
End ?
312
N
Y
Repeat ?
314
Y
N
Done

FIG. 4

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 745 769 A (CHOI YOUNG-GON) 28 April 1998 (1998-04-28) abstract; figures	1,16,27
A	US 3 755 782 A (HAAS L ET AL) 28 August 1973 (1973-08-28) abstract; figures	1,16,27
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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/26956

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